Actividades de la UPM con la IAEA en simulación neutrónica para reactores de transmutación con alto contenido en transuránidos

Alberto Abánades Velasco
Technical University of Madrid (UPM)
Contribuciones de:
Ignacio Álvarez Iberlucea
Pablo Cruz Galbán
Alfonso Bravo Graíño
Helena Sánchez Guerrero

UPM-GIT activities on ADS

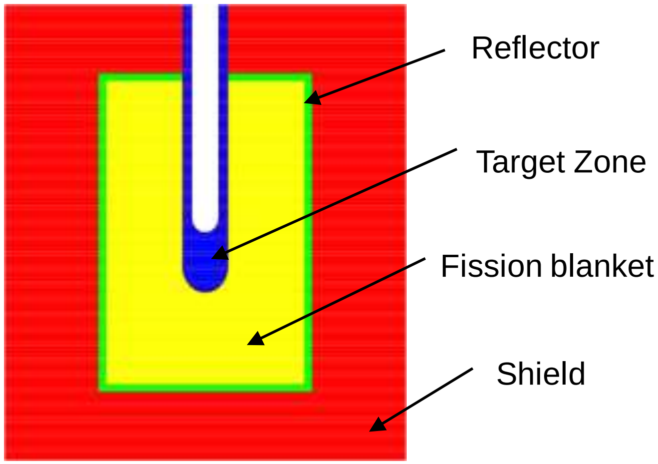
- Initial active involvement in cooperation with Prof. Rubbia, and experiments related to the Energy Amplifier project (FEAT, TARC, EU Roadmap, LAESA, ASCHLIM, PDS-XADS, CDT, IP-Eurotrans, FREYA).
- Coordination of previous CRP benchmark on the TARC experiment.
- Support to experimental activities regarding subcritical devices: criticality evaluation.
- Beam-nuclear core coherence. Spallation target modelling.
- Liquid metal thermal-hydraulics.
- Alternative reactor/system design.

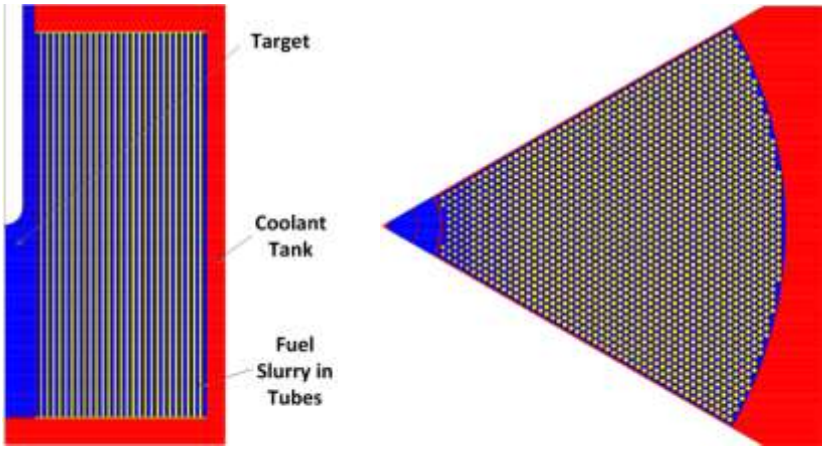
UPM activities

- UPM commitment was to participate in the following activities of the CRP “Accelerator Driven Systems (ADS) Applications and use of Low-Enriched Uranium in ADS“ doing Monte Carlo simulations (MCNPX + ADSLib 2.0 (ENDFB-VII)) in:
  - Argonne’s MAs liquid flowing fuel concept
  - DELPHI reactor
  - QUINTA experimental set-up
- In this presentation, the activities regarding the liquid metal flowing fuel concept will be shown.

Liquid metal reactor

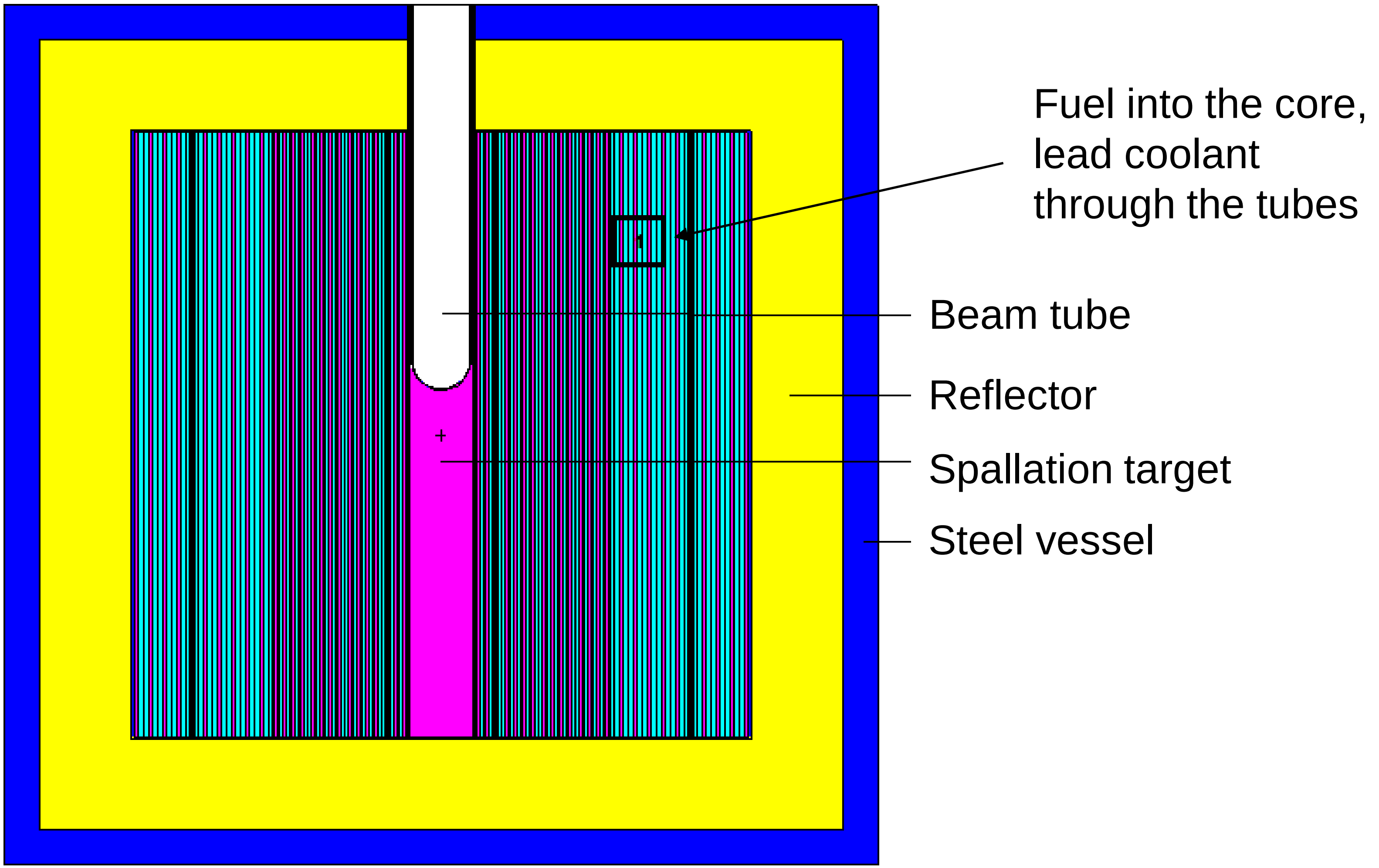
- 25 MW proton beam accelerator using 1 GeV protons with the molten lead target.
- Fission power is ~3 GW with ~0.98 k_{eff}.
- The spent nuclear fuel without uranium has been utilized. High concentrations of MAs are loaded to maximize its consumption.
- Actinide micro particles are suspended in the molten lead to form a mobile fuel slurry.
- Graphite reflector is used improve the neutron multiplication.
- Analysis shows that 4 to 5 ADS systems operated for 35 years can utilize the 115 tons of MAs.





Y. Cao, A. Talamo, Z. Zhong, and Yousry Gohar, Vienna, 2016

ANL's liquid metal reactor – First analysis

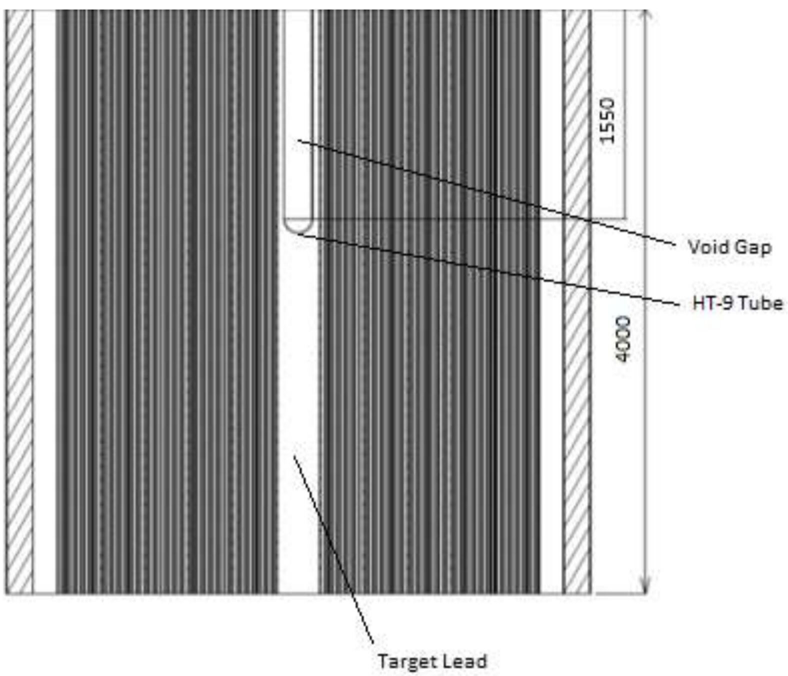


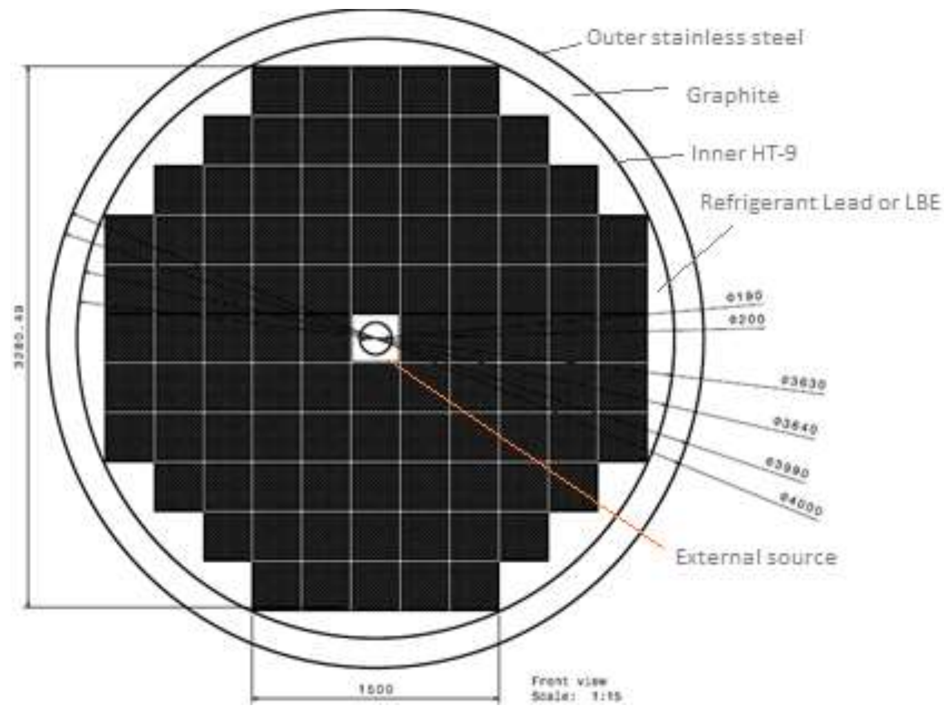
Liquid metal fuel reactor

- There was done a design of a liquid metal reactor based on Lead or Lead Bismuth Eutectic (LBE) with a slurry fuel composed of Lead and Minor actinides following the material input from ANL.
- Some main constraints for the reactor are:
  - Power: It has been sized to be able to produce of the order of 3GWth, with a power density of the order of 200 W/cm3.
  - The length of the active core of the order of 4 m, what provide the practical radius of the core.
  - For the practical implementation of the reactor, we have introduced a bundle-like structure to reduce coolant radial flow and increase structural stability.
  - Beam tube displaced along the beam direction axis to provide a centered neutron source distribution in the core, with 1 GeV proton beam.

Nuclear core

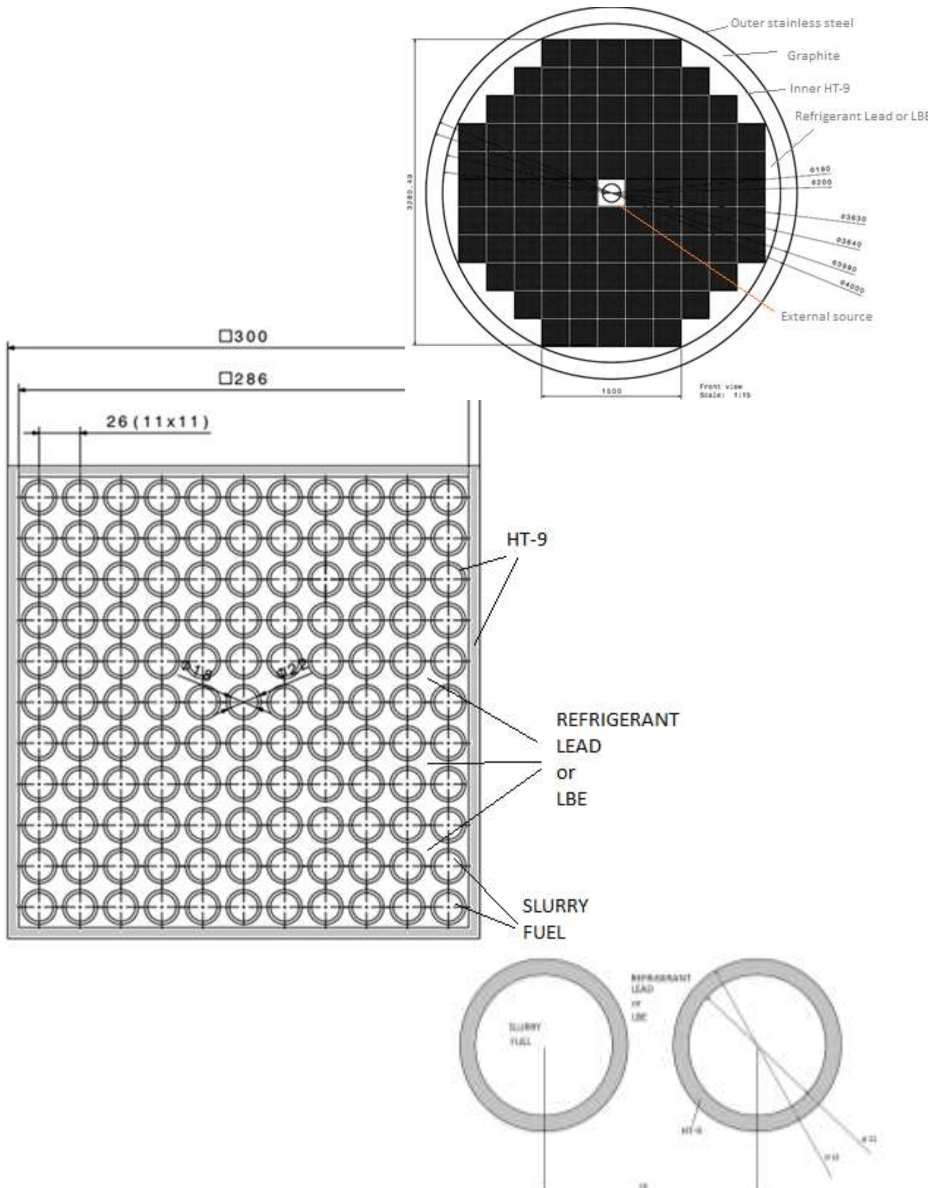
- Detailed view of the core, with a compact bundle distribution and z-displaced beam tube.





Core design

Parameter	Values
Core Height	400 cm
Core Diameter	400 cm
System Multiplication Factor	0.98
Outer Diameter of the Stainless Steel	400 cm
Outer Stainless Steel Thickness	1 cm
Outer Diameter of the Graphite	399 cm
Graphite Thickness	30 cm
Outer Diameter of the HT-9	364 cm
Inner HT-9 Thickness	1 cm
Number of Fuel Assembly	96
Fuel Assembly Material	HT 9
Fuel Assembly Height	4 m
Fuel Assembly Lenght	30 cm
Fuel Assembly Thickness	0.7 cm
Number of Fuel Pins per Assembly	121
Pin Material	HT-9
Outer Diameter of the Pin	2.2 cm
Pin Thickness	0.2 cm
External Source Material	HT-9
Proton Initial Energy	1 GeV
Spallation Target	Lead
Outer Diameter of the Source Tube	20 cm
Source Tube Thickness	1 cm
Refrigerant	Lead or LBE
Fuel Composition	Oxide actinide particles suspended or dissolved in liquid lead
External Source Mechanism	Proton Spallation



Fuel composition

Basic fuel composition according to the ANL specifications.

Isotope	Atom Density (at/b-cm)
U 235	4,986E-08
U 236	2,4824E-08
U 238	0,000005883
Np 237	0,00038763
Pu 238	0,000015655
Pu 239	0,00065197
Pu 234	0,00026282
Pu 241	0,000045967
Pu 242	0,000056718
Am 241	0,00068048
Am 242	0,000001058
Am 243	0,000069692
Cm 243	1,5052E-07
Cm 244	0,000007795
Cm 245	6,7181E-07
Cm 246	7,4342E-08
Pb 204	4,2547E-04
Pb 206	7,2530E-03
Pb 207	6,6189E-03
Pb 208	1,5618E-02
O 16	0,0043733

- Basic case: 9 % of the oxide actinide volume is suspended in liquid lead and the mixture of plutonium and uranium reaches 47.5 % of the actinides.
- It has been evaluated for this initial reactor the following features:
  - Core criticality
  - Coolant effects: Lead vs LBE.
  - Doppler effect
  - Fuel composition sensitivity,
  - Neutron flux in two representative positions.

Criticality calculation Keff

Evaluation of the core criticality with different actinide and Pu(+U) content of the slurry fuel,

% Actinide Vol	**% Pu**									
	10	**20**	**30**	**40**	**47,5**	**50**	**60**	**70**	**80**	**90**
2					0,42198		0,51597	0,59242	0,67125	0,74895
3					0,49346		0,60003	0,68844	0,77739	0,86877
4					0,55129		0,67029	0,76754	0,86607	0,96683
5					0,60495		0,73160	0,83493	0,93969	1,04963
6				0,57295	0,65266		0,78599	0,89460	1,00641	1,12090
7			0,50387	0,61368	0,69544		0,83632	0,95048	1,06711	1,18794
8		0,42630	0,53704	0,64992	0,73586		0,88039	1,00005	1,12219	1,24531
9	0,33890	0,45322	0,56785	0,68507	0,77333		0,92351	1,04562	1,16990	1,29931
9,5				0,70147	0,79157		0,94523	1,06678		
10	0,36157	0,47851	0,59801	0,71873	0,80954	0,83839	0,96393	1,08841	1,21837	
11	0,38369	0,50495	0,62674	0,74941	0,84415	0,87398	1,00115	1,12909		
12	0,40487	0,52835	0,65305	0,77960	0,87298	0,90624				
13	0,42574	0,55173	0,67797	0,80710	0,90382	0,93569				

Keff

Reactivity effect of the source

- The impact of the source gives the safety margin of the beam switch-off, and decrease when closer to critical.

Reactivity provided by the source, ρ (pcm)					
% Vol	% Pu				
	50	60	70	80	90
3					13366
4				13569	2807
5				5540	
6			10300		
7			4414		
9		7181			
9.5		4907			
10		3057			
12	8875				
13	5883				

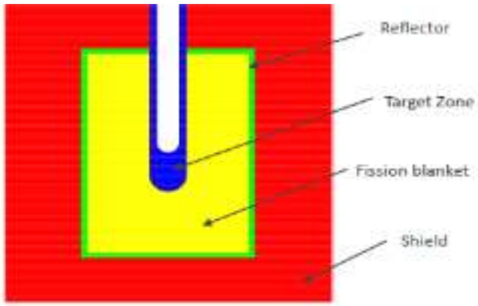
β~250 pcm

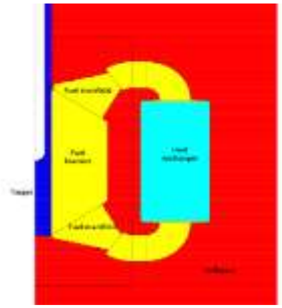
Doppler effect

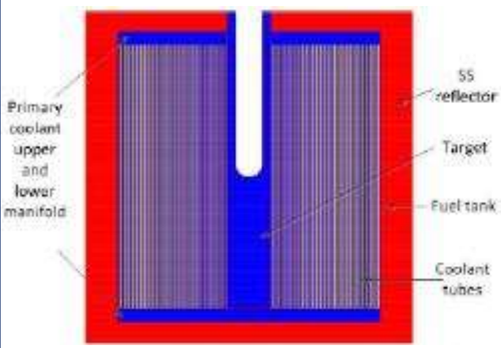
- We have evaluated the Doppler effect between ambient and 900 K.

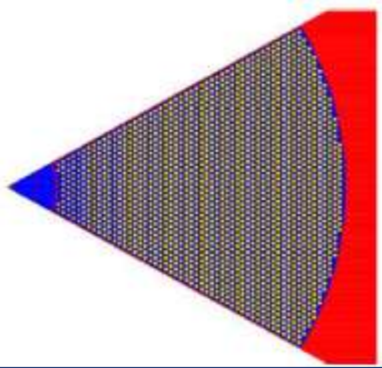
αf, (pcm/ºC)					
% Vol	% Pu				
	50	60	70	80	90
3					-0,434
4				-0,300	-0,198
5				-0,177	
6			-0,204		
7			-0,114		
9		-0,150			
9.5		-0,095			
10		-0,083			
12	-0,133				
13	-0,092				

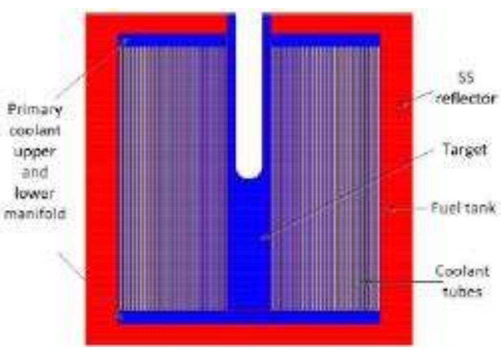
Modelo del Argonne National Laboratory
CONFIGURACIÓN DEL MODELO

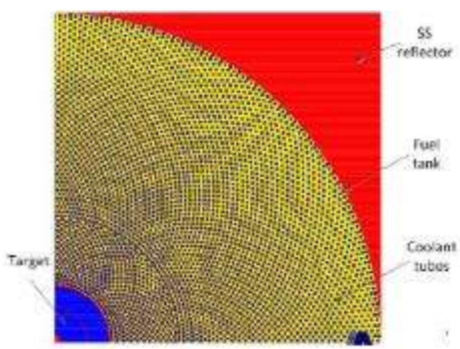






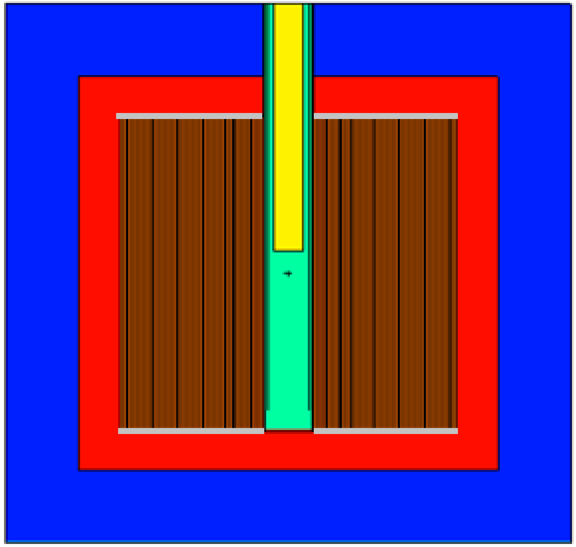


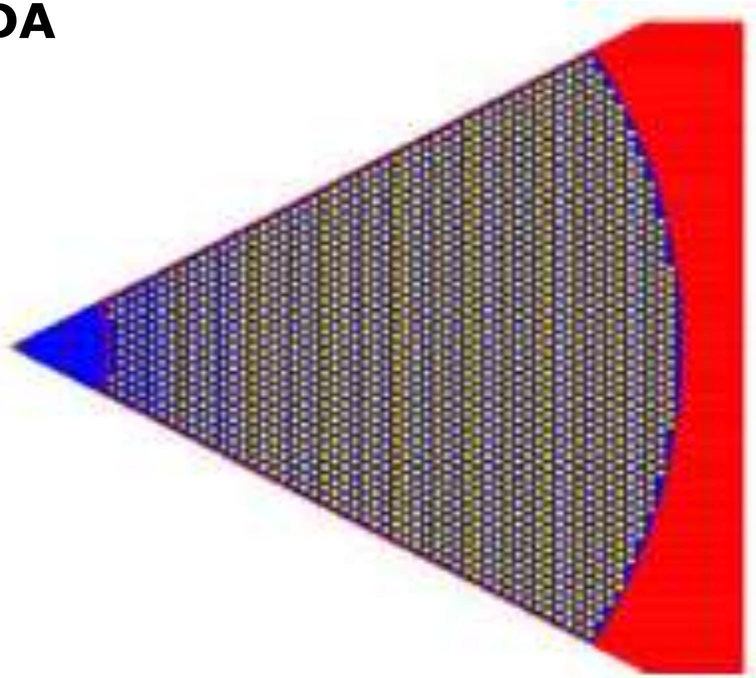




- **Combustible líquido**
  - ✓ Alimentación continua
  - ✓ Adaptación a cambios de composición
  - ✓ Controlar reactividad variando alimentación
  - ✓ Menores tensiones mecánicas

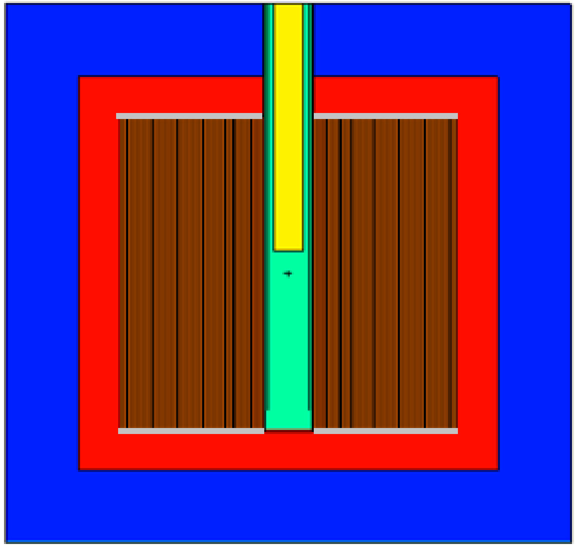
CONFIGURACIÓN ORDENADA





ZONA	RADIO	COLUMNAS	Nº TUBOS
1	1,1 cm	1	4
2	1,15 cm	2-5	46
3	1,35 cm	6-12	119
4	1,45 cm	13-56	1688

SIMULACIÓN DEL MODELO

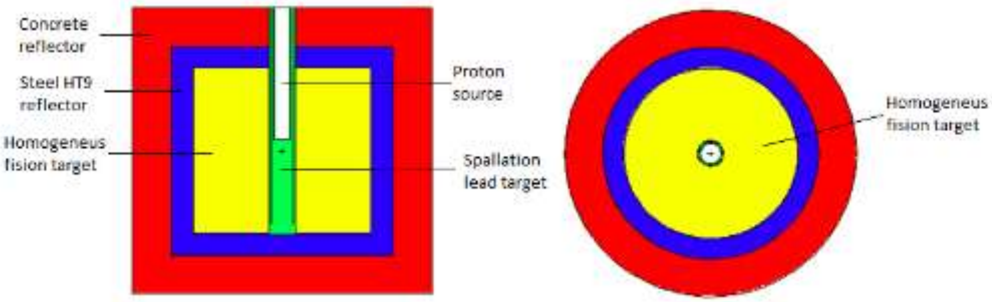


- Funcionamiento normal
- F. anormal
  - Vaciado del Pb
  - Inundación con agua

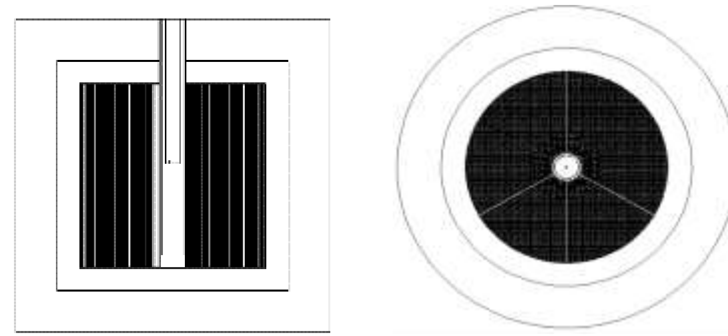
MCNPX

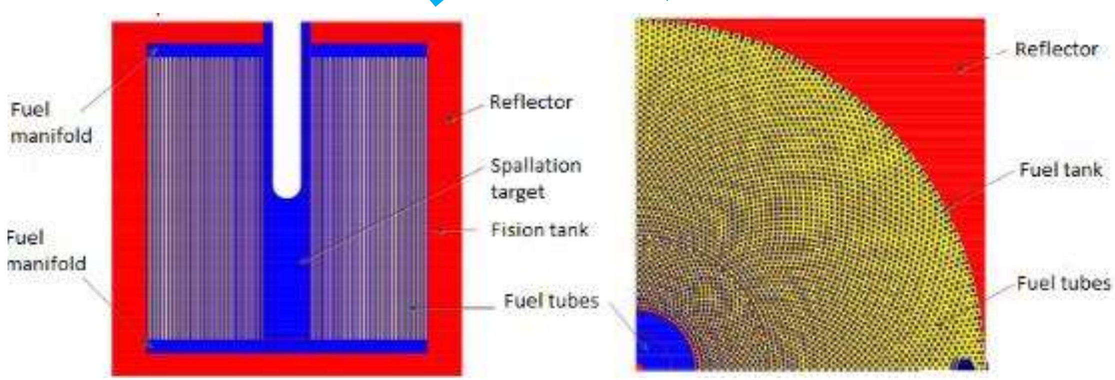
Geometrías desarrolladas
GEOMETRÍAS

GEOMETRÍA SIMPLE



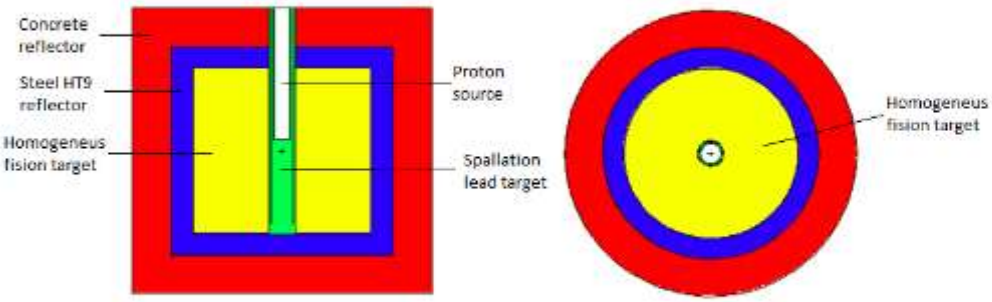
GEOMETRÍA COMPLEJA



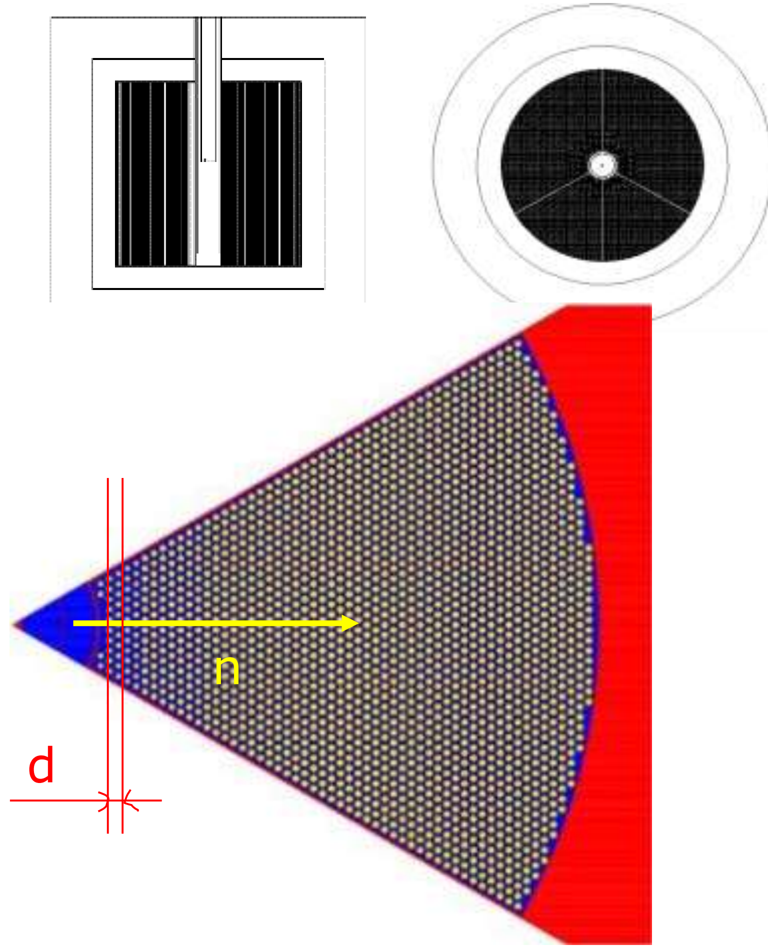


Geometrías desarrolladas
GEOMETRÍAS

GEOMETRÍA SIMPLE



GEOMETRÍA COMPLEJA



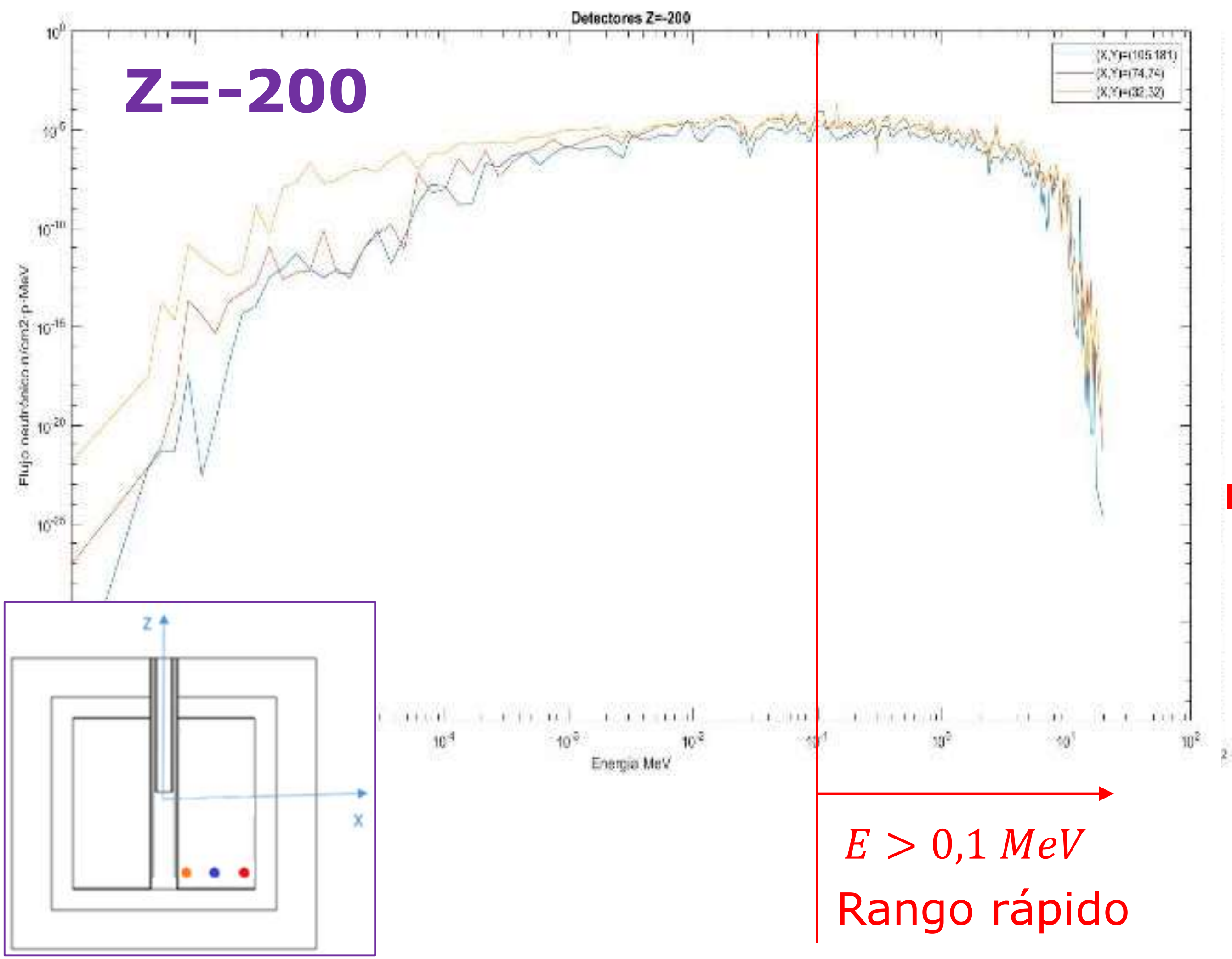
Núcleo homogéneo

Menores tiempos simulación

	k_{eff}	k_s
Geometría simple	0.9766	0.9868
Geometría compleja	0.9552	0.9689

- Valores adecuados ADS: $0,95 - 0,98$
- Variación entre geometrías: $\sim 0,02$

Resultados
DISTRIBUCIÓN ENERGÉTICA



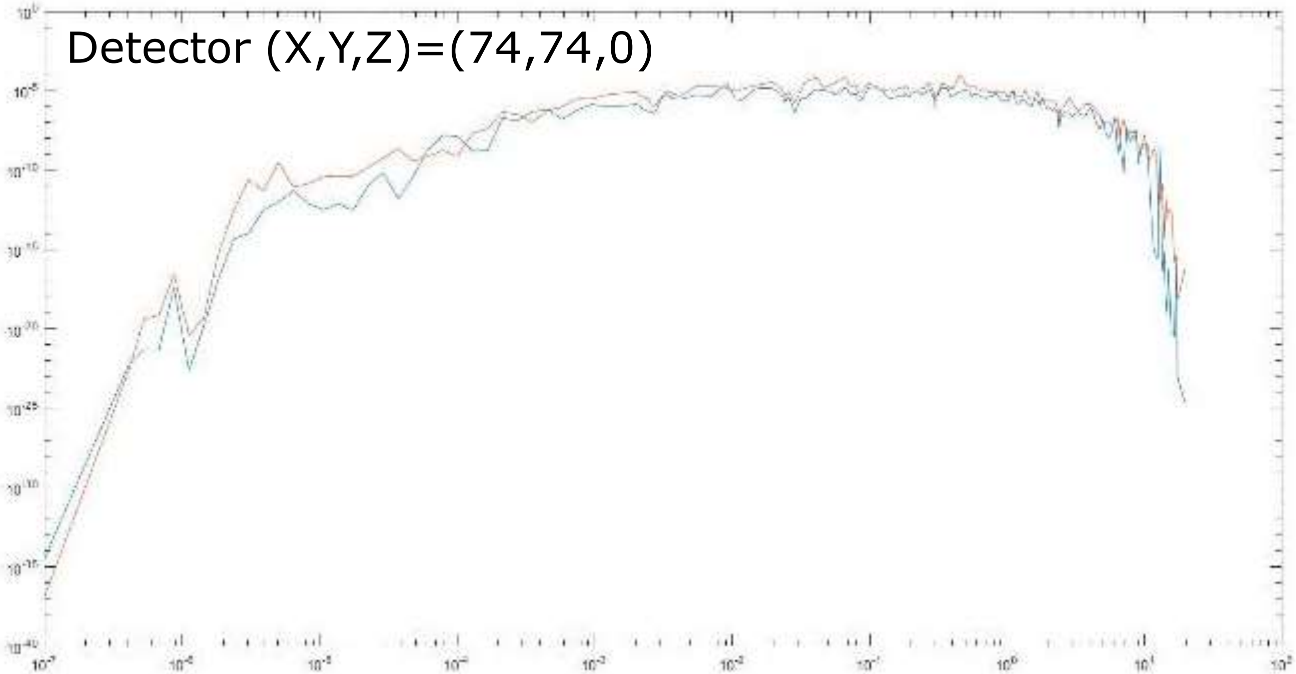
Flujo máximo de neutrones

$$E \sim 10^{-3} - 1\ MeV$$

➡ **Homogeneidad energética**

· Quemado combustible homogéneo

Resultados
DISTRIBUCIÓN ENERGÉTICA



- Fidelidad entre ambas geometrías
- Ahorro tiempo simulación: **25 días → 34 horas**

Resultados
ACCIDENTES-VACIADO DEL PLOMO

	k_{eff}
Vacío	1.0327
Aire	1.03136

➡ Intrínsecamente inestable sin refrigerante

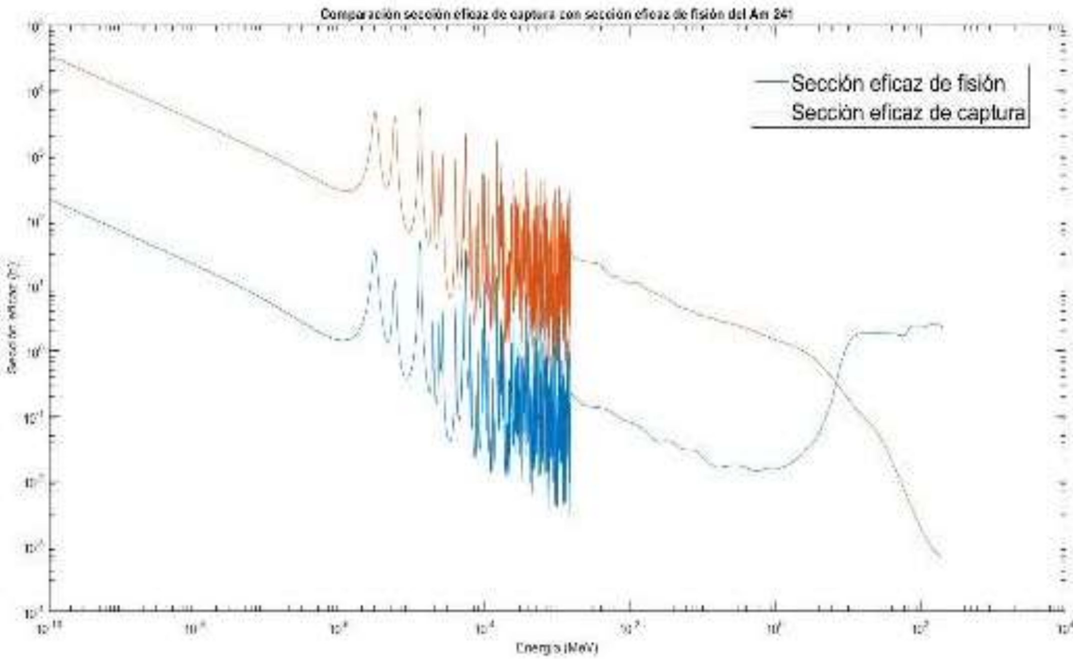
Resultados
ACCIDENTES-INUNDACIÓN CON AGUA

	k_{eff}	k_s
Inundado con agua	0,83035	0,8356

$$\frac{neutrones\ capturados}{neutrones\ \ sometidos\ a\ fisión}$$

=2,03
Funcionamiento normal

=2,82
Inundado con agua



Conclusiones

- Se ha presentado una parte de las actividades que se han realizado en un CRP con OIEA.
- Se ha utilizado la librería ADSlib, basada en ENDFB VII.
- Necesidad de evaluación de secciones eficaces e incertidumbres de actínidos para aplicación de actínidos en flujos de alta energía.
- Los datos nucleares a alta energía pueden ser de alta importancia para evaluaciones de seguridad, de diseño, en reactors rápidos orientados a transmutación,